GOCE – Last days' orbits

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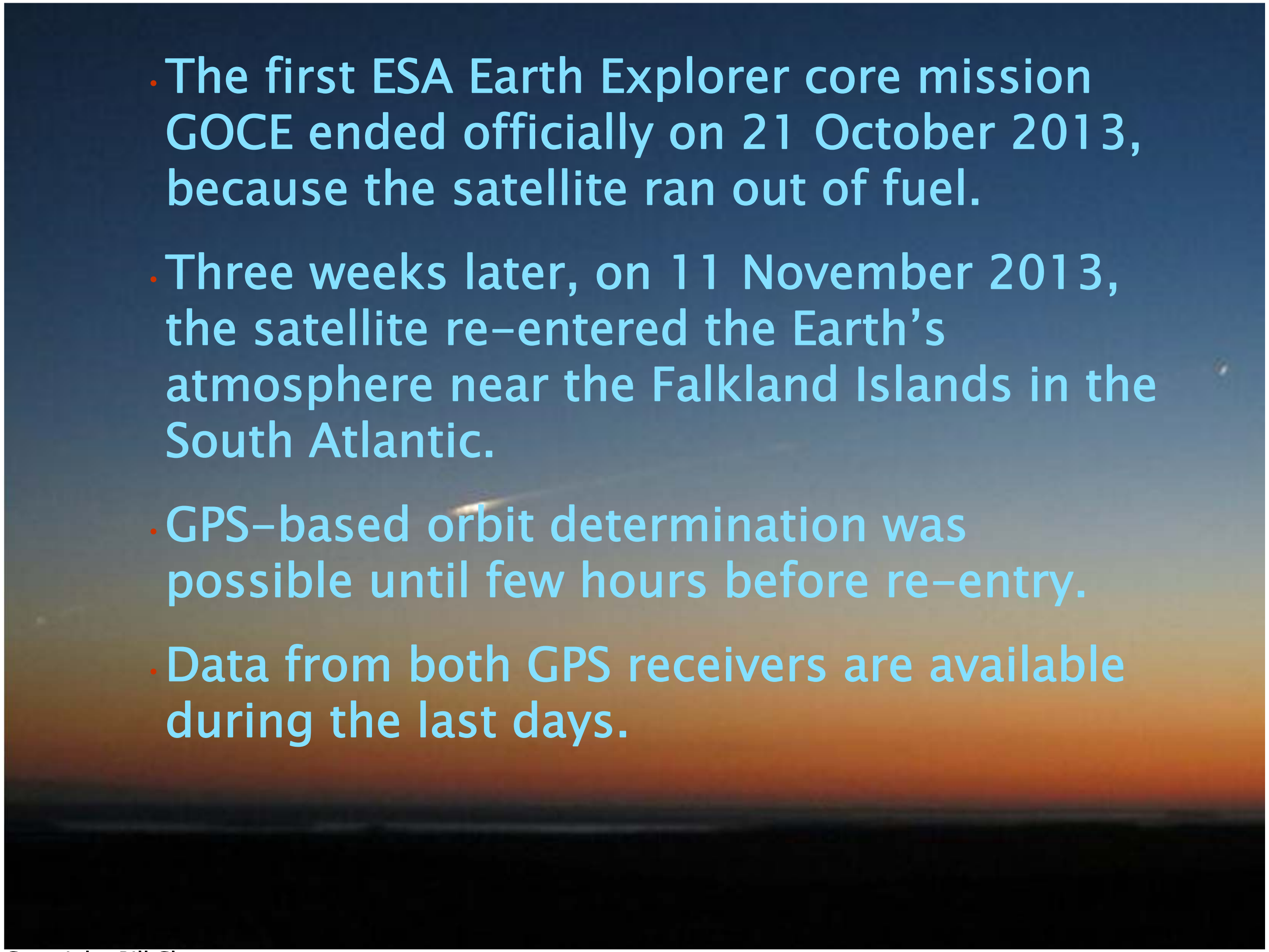
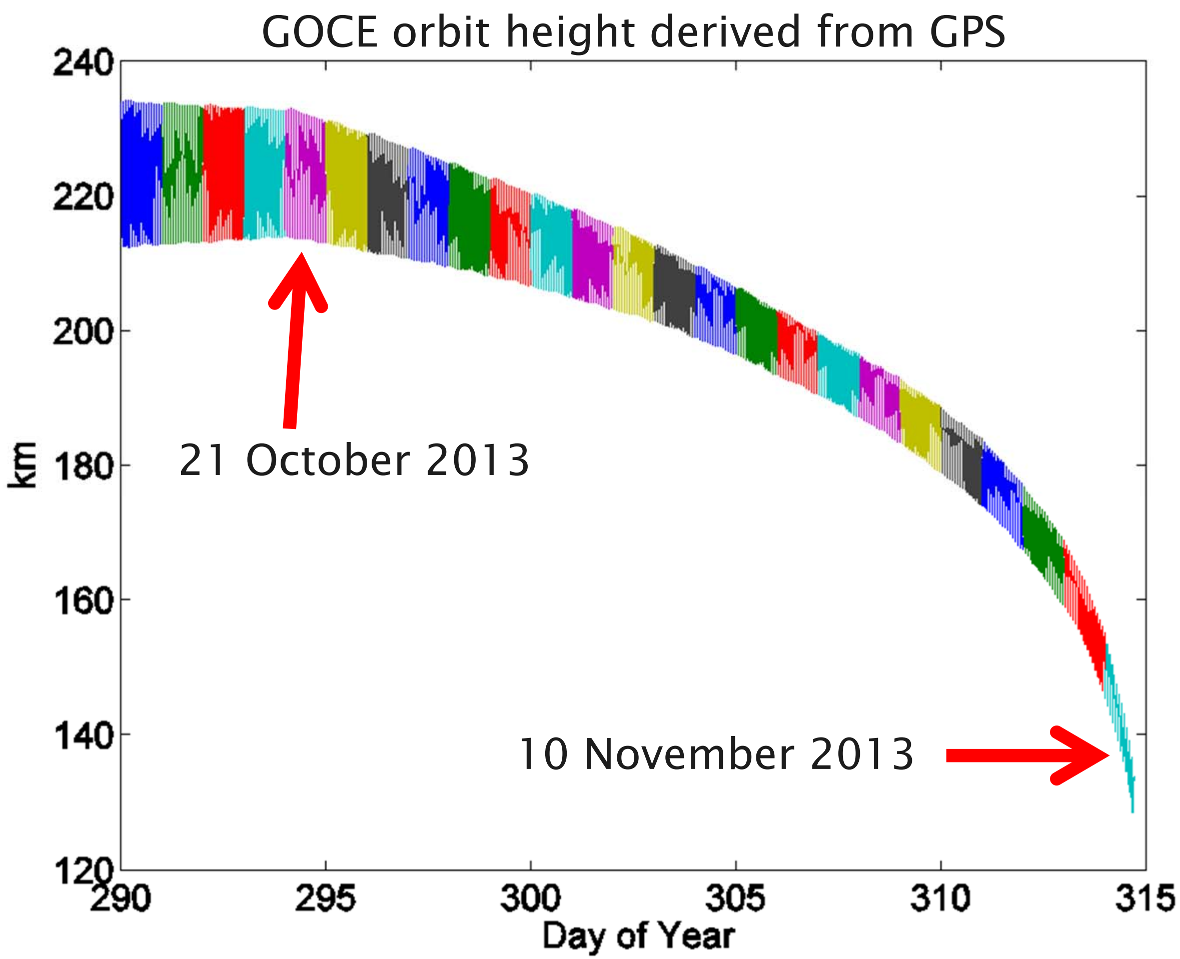
Background and Motivation



- The first ESA Earth Explorer core mission GOCE ended officially on 21 October 2013, because the satellite ran out of fuel.
- Three weeks later, on 11 November 2013, the satellite re-entered the Earth’s atmosphere near the Falkland Islands in the South Atlantic.
- GPS-based orbit determination was possible until few hours before re-entry.
- Data from both GPS receivers are available during the last days.

Background and Motivation



- Last available GPS measurements: **10 November, 17:15:20 UTC**

Background and Motivation

- In the frame of the European GOCE Gravity Consortium (EGG-C) AIUB was responsible for the generation of the GOCE Precise Science Orbit (PSO) product => reduced-dynamic and kinematic orbit.
- Internal validation: Orbit overlap analysis and differences between reduced-dynamic and kinematic orbits for consistency checks.
- External validation: Satellite Laser Ranging (SLR) measurements.
- Reduced-dynamic orbits were generated with the same orbit parameterization for the entire mission.

Two main questions for this study:

- How can the orbits be validated, because SLR measurements are no longer available (only three passes)?
- Is the orbit parameterization of the reduced-dynamic orbit still reasonable for the last three weeks of GOCE?

What have we done?

We look at the following possibilities for validation:

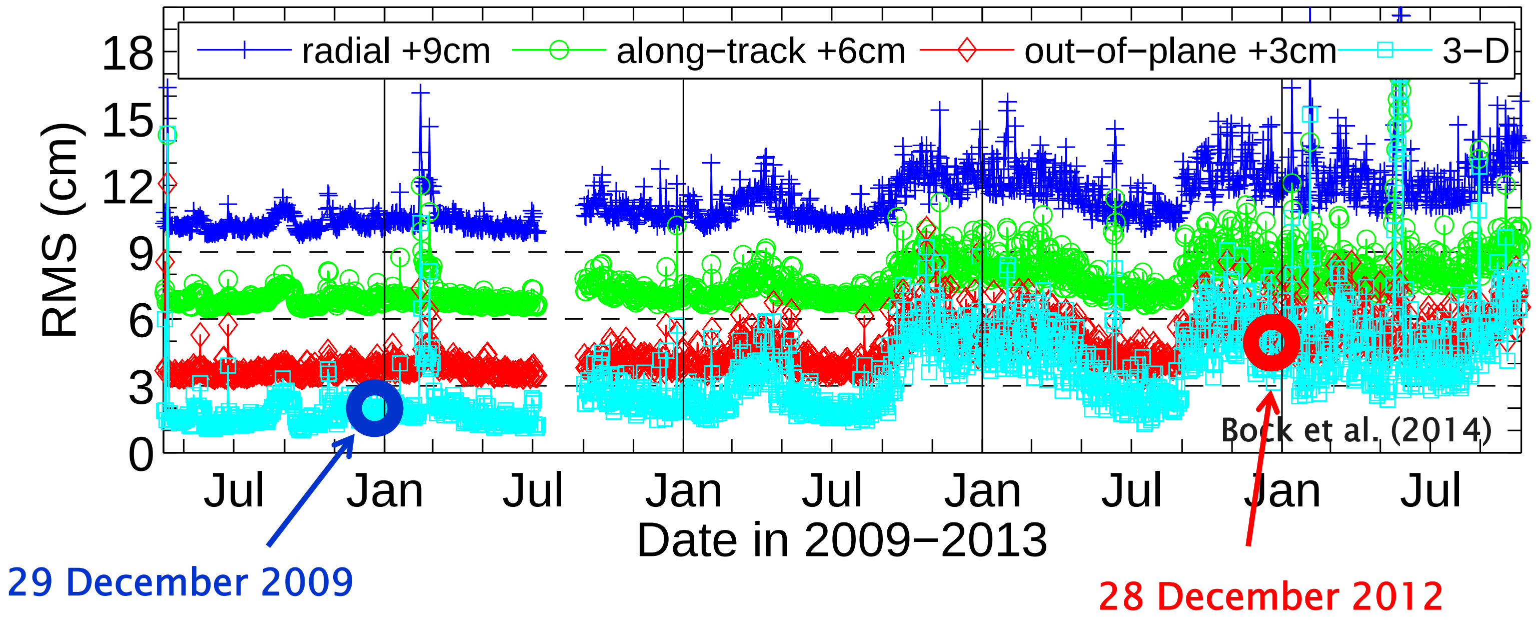
- Orbit differences between reduced-dynamic and kinematic orbit.
- Comparison of orbit solutions from the two GPS receivers.

Parametrization of the reduced-dynamic orbit is adapted by

- changing the constraints of the empirical parameters
- replacing the background models (e.g., gravity field model) by more recent models

GOCE internal orbit validation

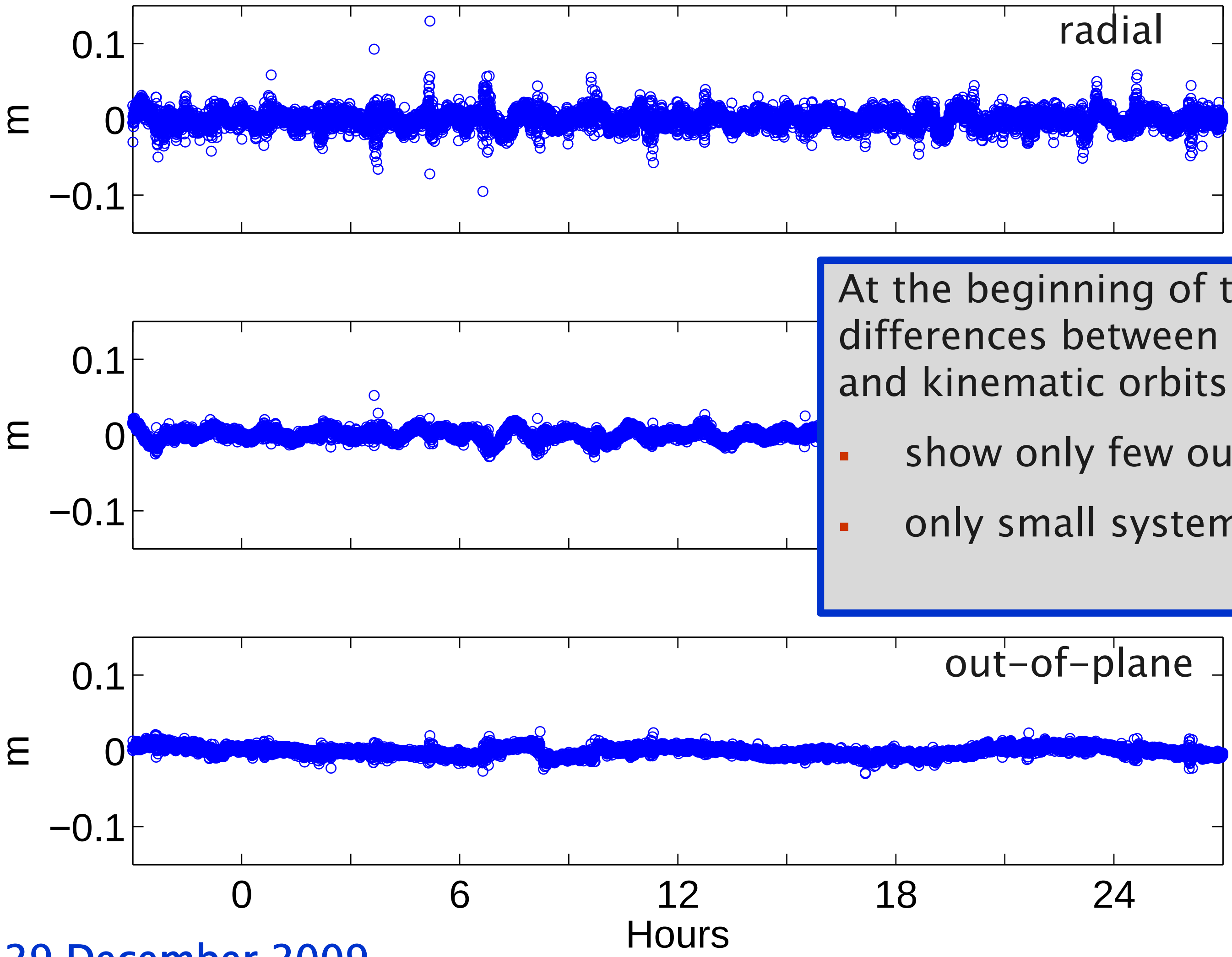
RMS of differences between red.-dyn. and kinematic orbits during official mission time



Differences between reduced-dynamic and kinematic orbits

- show consistency between the two orbit types and
- reveal data problems and gaps in the kinematic orbit

Differences red.−dyn. ⇔ kinematic orbits

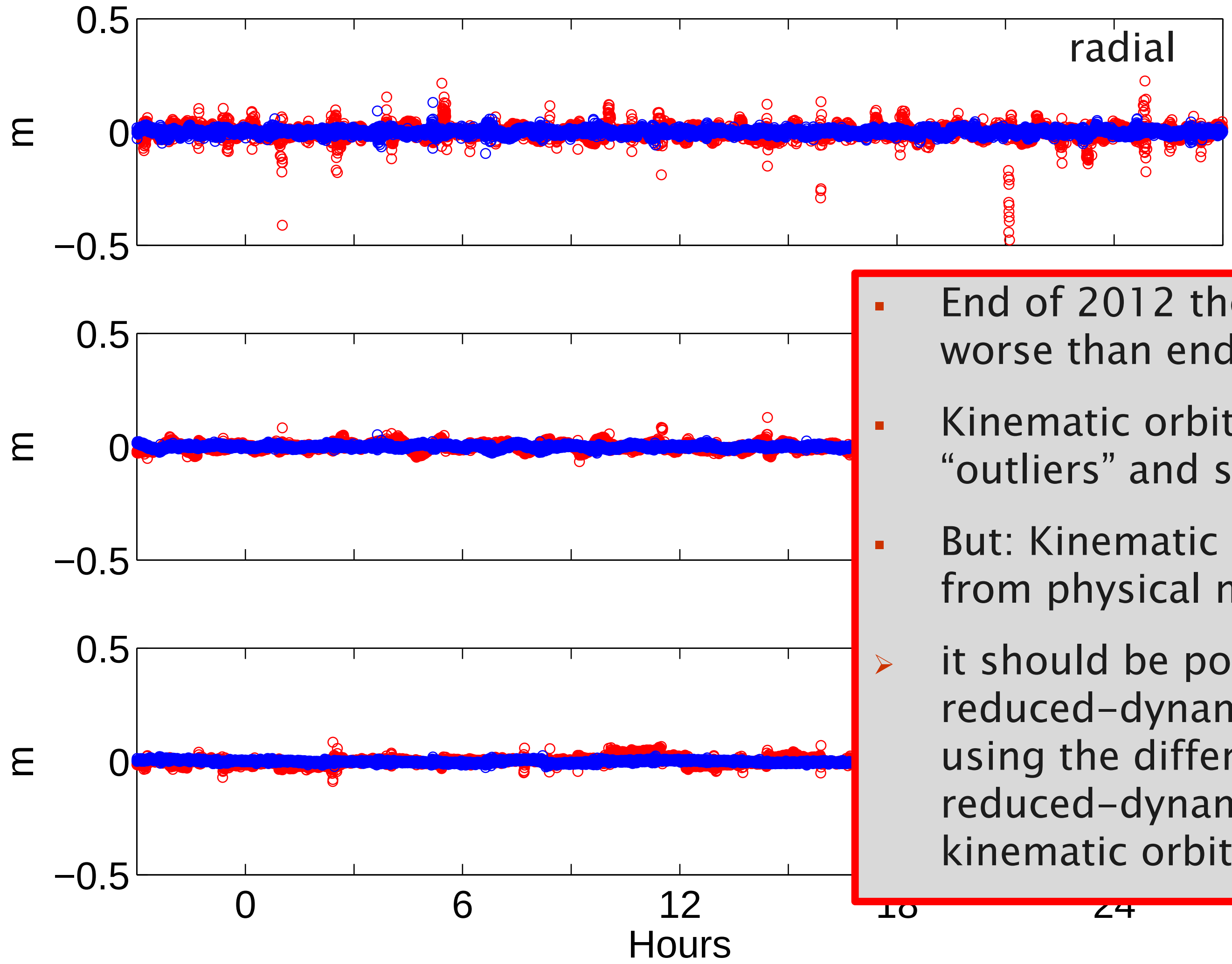


At the beginning of the mission the differences between reduced−dynamic and kinematic orbits

- show only few outliers and
- only small systematics are present

29 December 2009

Differences red.-dyn. ⇔ kinematic orbits

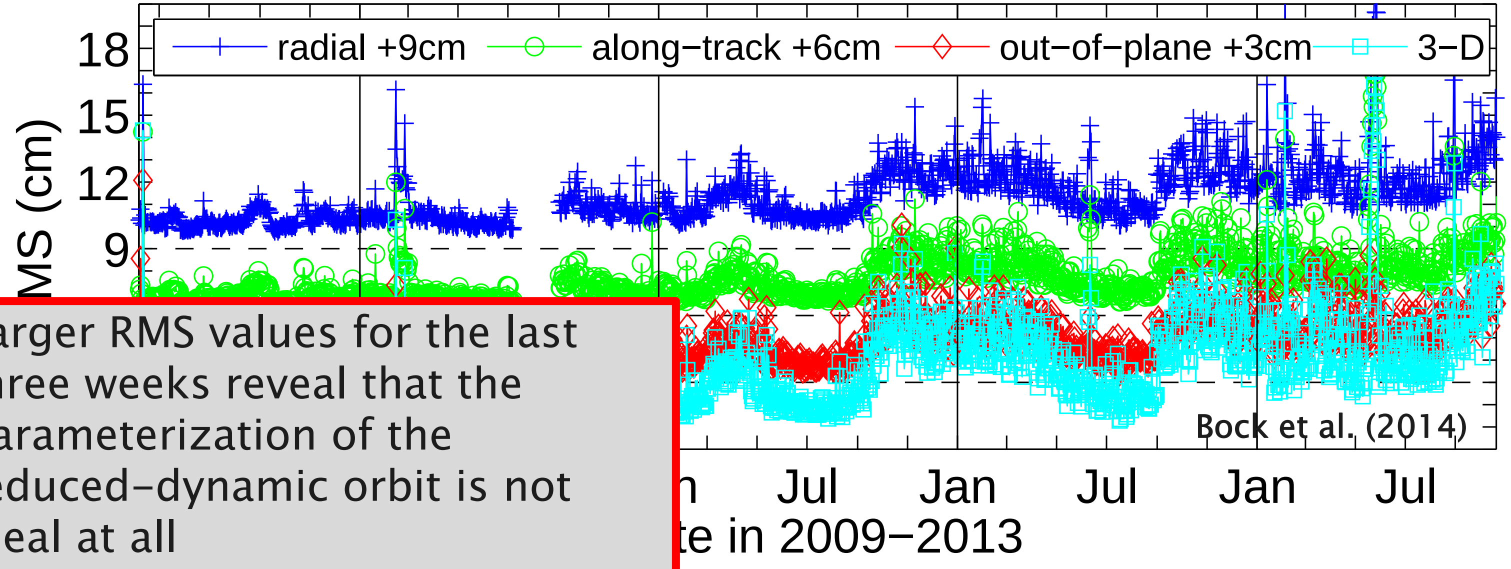


28 December 2012 and 29 December 2009

- End of 2012 the data quality is worse than end of 2009
- Kinematic orbit shows more “outliers” and systematic effects
- But: Kinematic orbit is independent from physical models and therefore
- ➢ it should be possible to validate the reduced-dynamic orbit modeling using the differences between the reduced-dynamic and the kinematic orbits

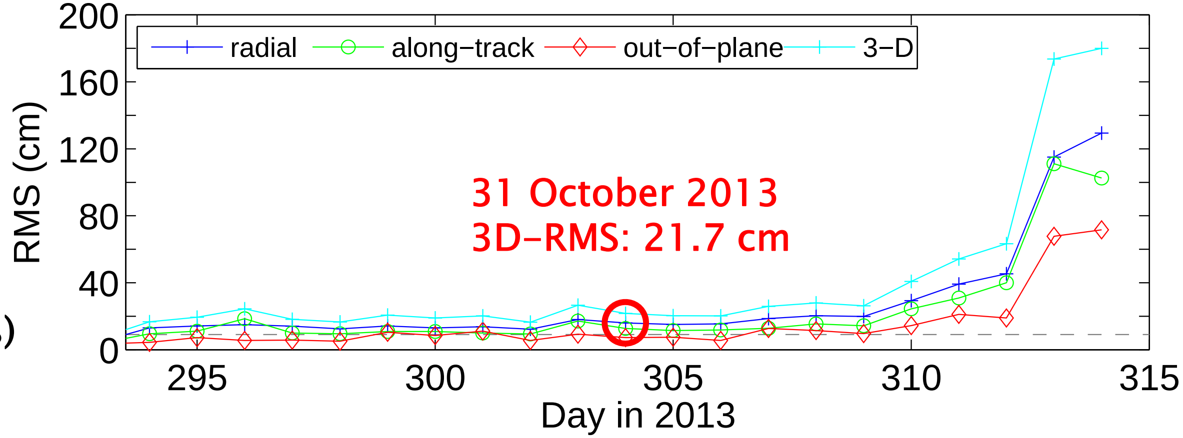
GOCE internal orbit validation

RMS of differences between red.-dyn. and kinematic orbits for official mission



- Larger RMS values for the last three weeks reveal that the parameterization of the reduced-dynamic orbit is not ideal at all

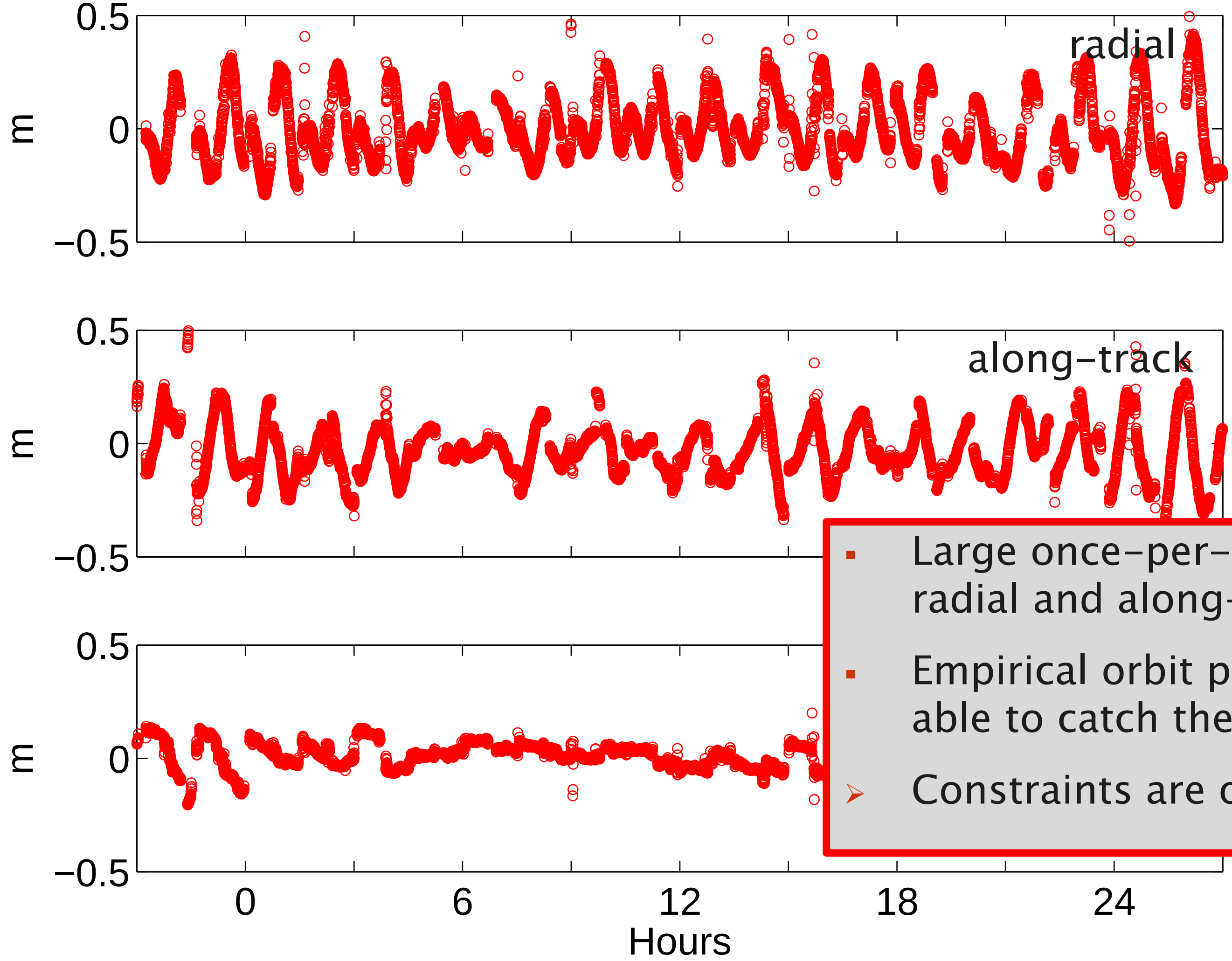
Last three weeks



SLR validation (3 passes)

2.64 ± 5.52 cm

Differences red.–dyn. ⇔ kinematic orbits

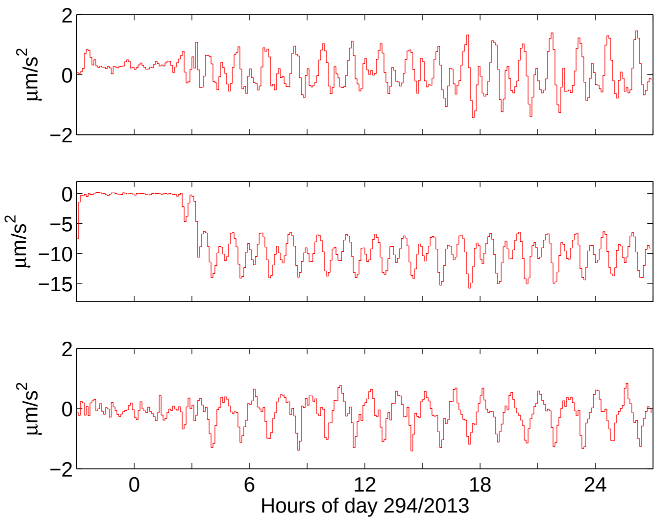


- Large once-per-revolution signal in radial and along-track component
- Empirical orbit parameters are not able to catch the full signal
- ➢ Constraints are obviously too tight

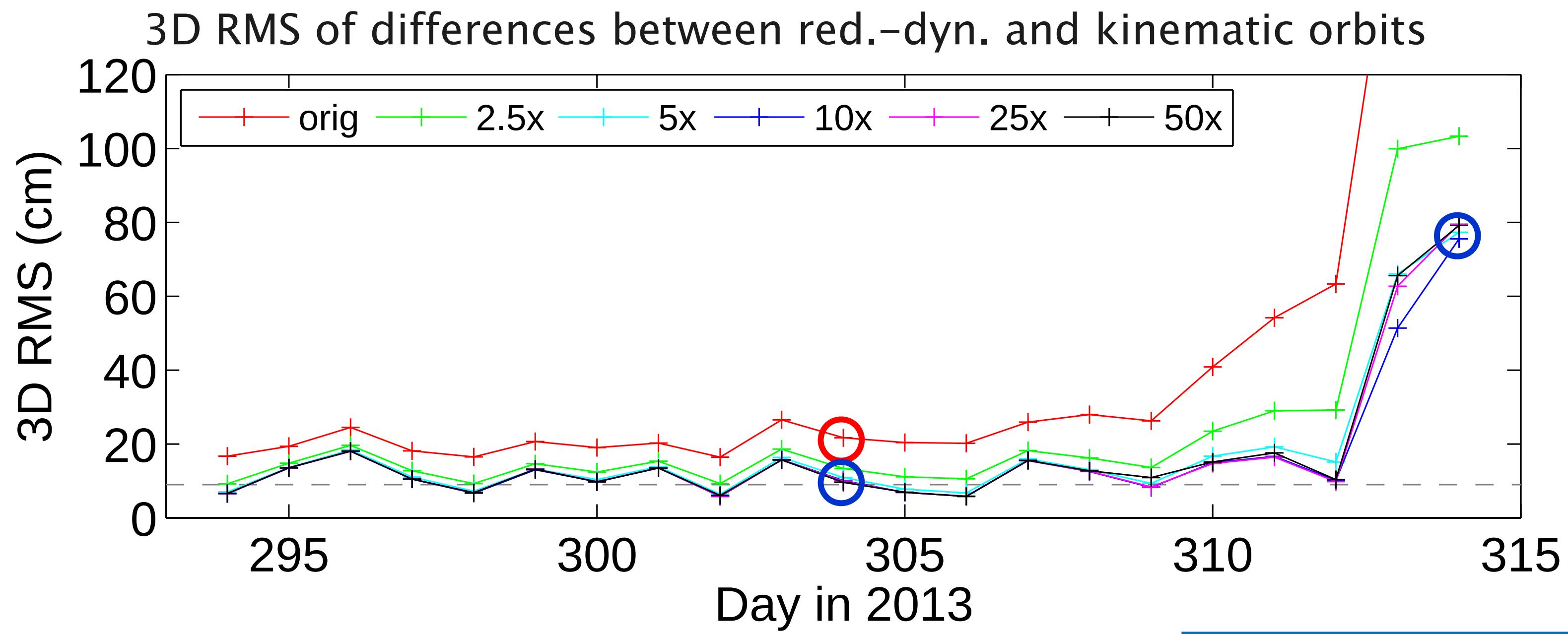
Original solution; 31 October 2013

Reduced-dynamic orbit determination

- 30 h processing batches (not for the last 10 days), 10 s sampling, undifferenced processing, ionosphere-free linear combination, CODE Final GNSS orbits and clocks (5 s) and Earth Rotation Parameters
- Orbit models and parameterization:
  - EIGEN5S 120x120, FES2004 50x50 (fixed by GOCE Standards)
  - Six initial orbital elements
  - Three constant accelerations in radial, along-track, out-of-plane
  - 6-min piece-wise constant accelerations in radial, along-track, out-of-plane ($2*10^{-8}$ m/s^2)
- Test solutions with weaker constraints:
  - 2.5 x $2*10^{-8}$ m/s^2
  - 5 x
  - 10 x
  - 25 x
  - 50 x



Solutions with weaker constraints



- Test solutions with weaker constraints show better consistency with kinematic orbits.
- Differences between 5x and 50x weaker constraints are marginal.
- Except the very last days, these solutions are acceptable.
- SLR validation is not very meaningful because of the very small number of passes

SLR validation RD orbits

2.64 ± 5.52 cm

7.25 ± 7.55 cm

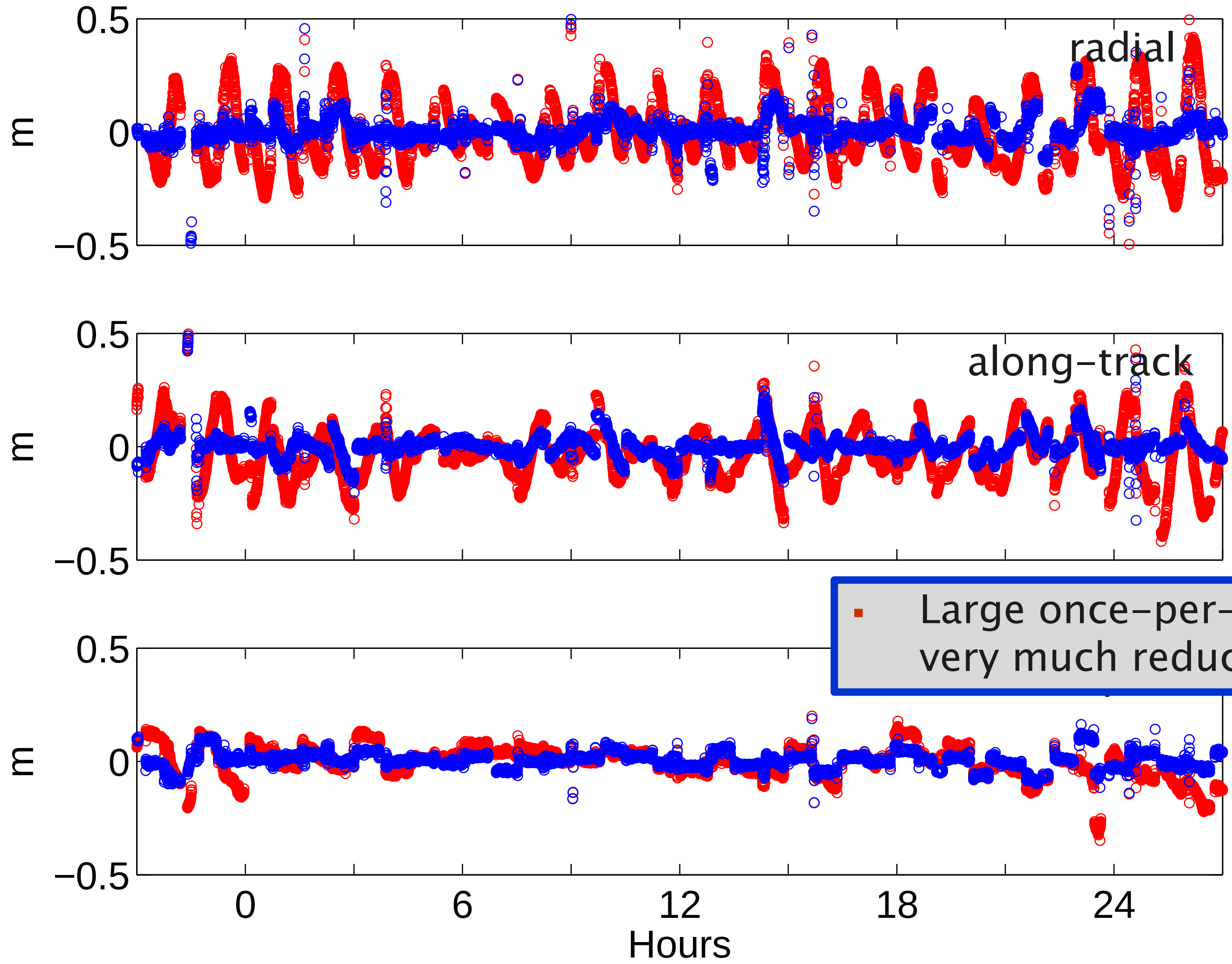
4.76 ± 5.03 cm

3.78 ± 4.07 cm

3.43 ± 3.73 cm

3.40 ± 3.73 cm

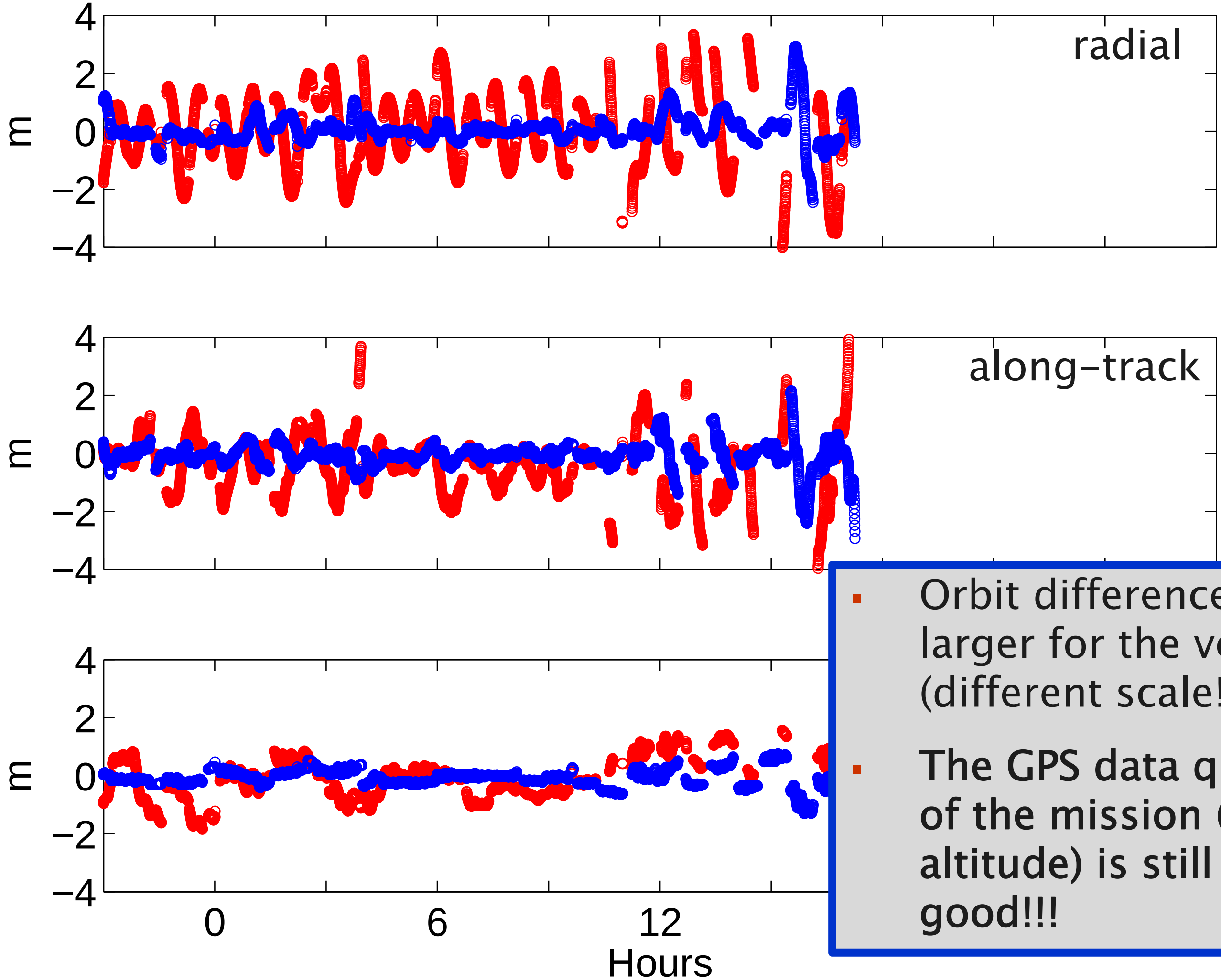
Differences red.-dyn. ⇔ kinematic orbits



- Large once-per-revolution signal is very much reduced

Original solution and 10x weaker constraints; 31 October 2013

Differences red.−dyn. ⇔ kinematic orbits



- Orbit differences are significantly larger for the very last hours (different scale!!)
- The GPS data quality at this stage of the mission (150 – 130 km altitude) is still surprisingly good!!!

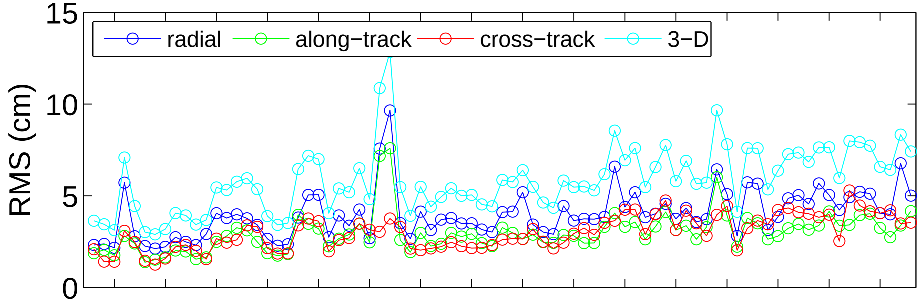
Original solutions and 10x weaker constraints; 10 November 2013

Comparison with second GPS receiver

RMS of differences between red.-dyn. and kinematic orbits: 1 Aug – 20 Oct 2013

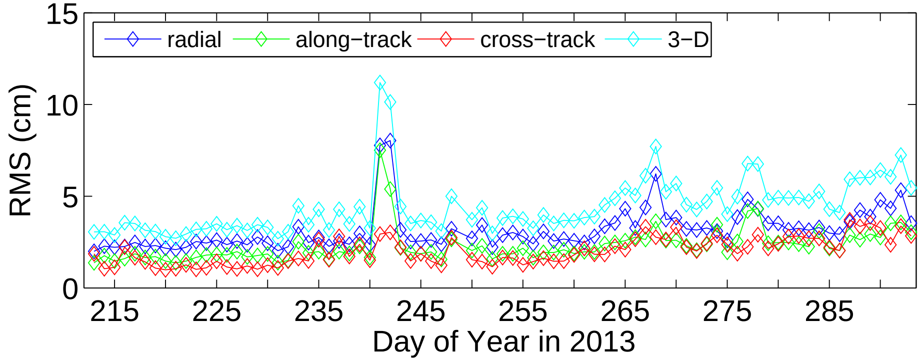
SSTI-A

Mean 3D-RMS: 5.86 cm



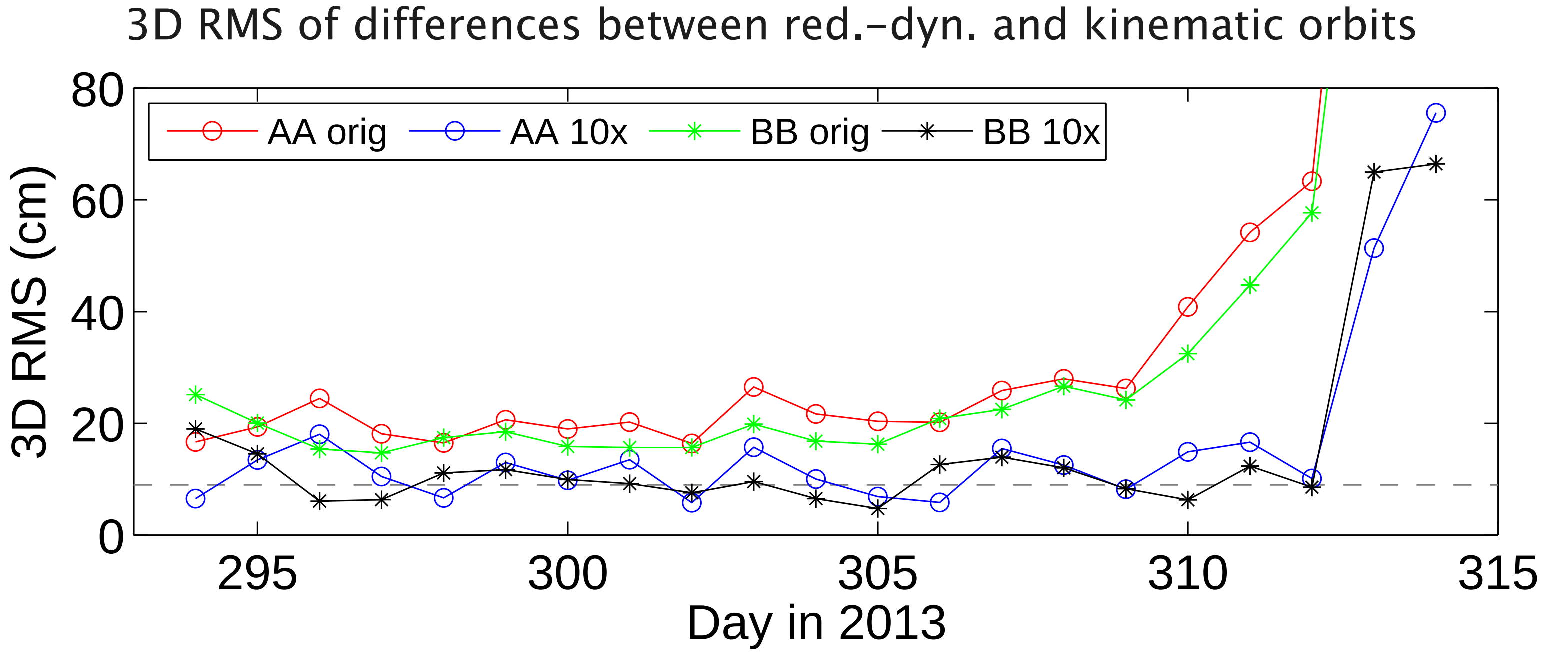
SSTI-B

Mean 3D-RMS: 4.43 cm



- Since 1 August 2013 both GPS receivers were running
- SSTI-B was operated with an updated firmware version, which reduced the number of data losses on L2 but led to a slight increase of the carrier phase noise.

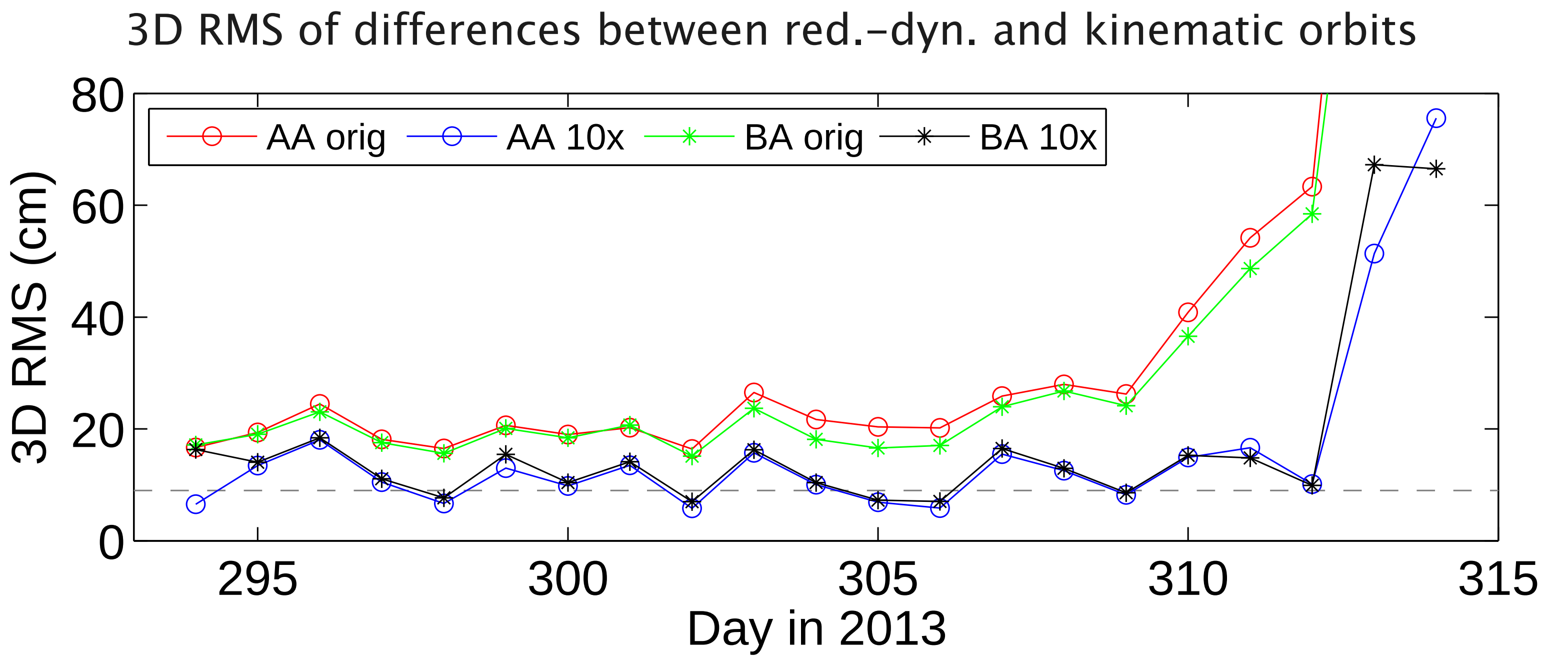
Solutions with weaker constraints – second GPS



- Orbit differences from SSTI-B show in average slightly better performance
- SLR validation is only a snap-shot from the three passes

SLR validation RD orbits (3 passes)	
SSTI-A	SSTI-B
2.64 ± 5.52 cm	10.54 ± 11.87 cm
3.78 ± 4.07 cm	2.94 ± 4.28 cm

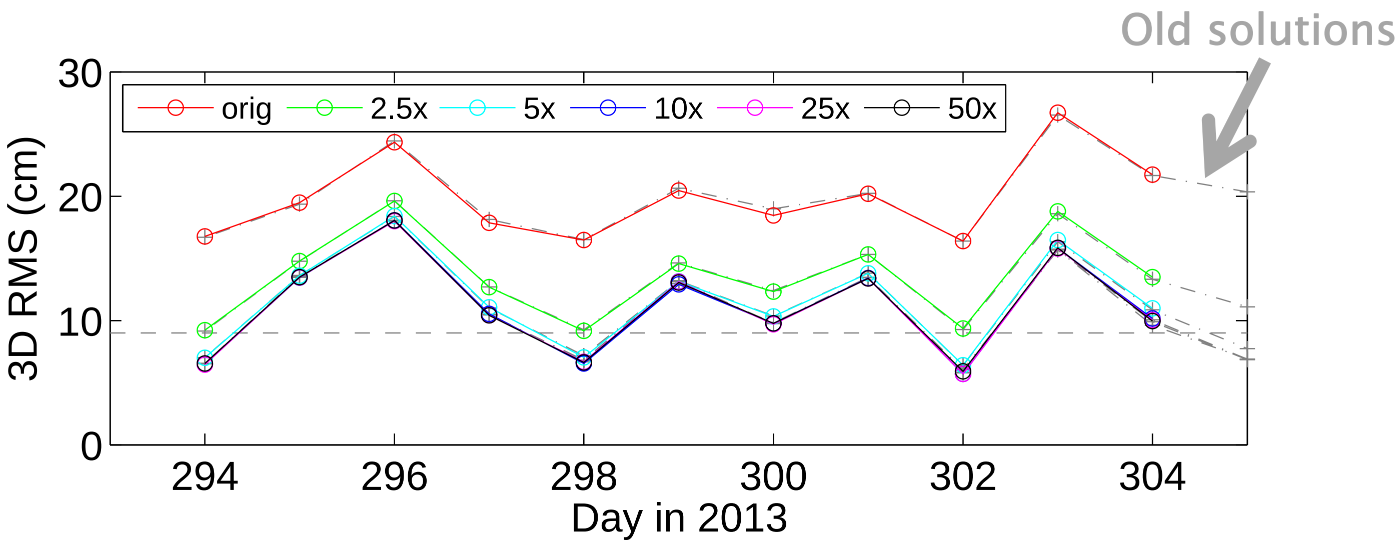
Solutions with weaker constraints – second GPS



- If we look at the differences between the reduced-dynamic orbits from SSTI-B and the kinematic orbits from SSTI-A, the differences are very similar
  - Reason for this is the quality of the kinematic orbit, which is slightly better for SSTI-B because of less data gaps
  - The differences in the quality of the kinematic orbit are not critical for the validation of the reduced-dynamic orbit

Improved background modeling

- In order to improve the background models the gravity field model EIGEN5S 120x120 is replaced by GOCO03S 200x200 for the first 11 days of the decay phase.
- Test solutions with original and weaker constraints are repeated.



- No improvements with respect to the old solutions can be noticed with the better gravity field model.
- Other perturbations, mainly the atmospheric drag, are dominating.

Summary

- How can the orbits of the last days of GOCE be validated ?=> The differences between kinematic and reduced-dynamic orbits may be used for validation, because the quality of the kinematic orbit is still very good.
- Is the orbit parameterization of the reduced-dynamic orbit still reasonable for the last three weeks of GOCE? => No, the constraints are too tight; 10x weaker constraints are reasonable.
- Orbits from both GPS receivers are as expected very similar and comparison confirms the results from the main GPS receiver.
- Updates in the background modeling of the reduced-dynamic orbit determination did not improve the results of the reduced-dynamic orbits, because other perturbations, in particular atmospheric drag, are dominating.